Optical drift test of the long delay line stations on the Navy Prototype Optical Interferometer

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ABSTRACT

At the Navy Prototype Optical Interferometer (NPOI), during stellar fringe acquisition and tracking, optical stations along the NPOI vacuum line array remain in passive mode. Optical drift amplitude and rate must remain below certain limits lest stellar acquisition and fringe tracking become unachievable. Subsequent to each observation, relay mirrors are reconfigured within the long delay line stations to provide appropriate constant delays. The placement of these mirrors must be reliable and repeatable within certain tolerances. We describe the results of drift tests conducted on the current long delay line stations.

Key Words: NPOI, thermal drift tests, long delay lines, opto-mechanical

1. INTRODUCTION

The Navy Prototype Optical Interferometer (NPOI)[1] has been in operation at the Lowell Observatory site on Anderson Mesa, AZ, since 1996. The current array configuration consists of six siderostats, four in fixed locations and two that are moveable, with a maximum baseline length of 67 m. Light from each siderostat is conveyed through a vacuum feed pipe to the array center, and from there northwestward to the optics lab, where a periscope lowers the beam and directs it westward toward a continuously-adjustable delay line (a "fast delay line," or FDL) that provides from 0 to 35 m of optical path. The light then exits the FDL and proceeds to the beam combiner.

In the near future, one of the siderostats will be moved further from the array center, and the maximum baseline will become 97 m. When the NPOI is complete, baselines up to 437 m will be available. In order to use the long baselines, the NPOI requires supplemental delay lines in addition to the FDLs. Without these supplemental delay lines ("long delay lines," or LDLs), the sky coverage of the NPOI would be severely constricted (see Fig. 1).

An LDL consists of a 100 m vacuum tank with six stations along its length. Most of the LDL length is outside the lab building. Each station has two mirrors, side by side, each with a positioning mechanism (the "popup" mechanism) that can raise its mirror into the light path. When the LDLs are installed and integrated into the NPOI, light from the siderostats will enter the optics lab as before, and be reflected downward by the top periscope mirror. The single mirror currently at the bottom of the periscope will be replaced with three mirrors. The first mirror will reflect the light northward into an LDL instead of westward toward an FDL. The light will travel along the east side of the LDL and reflect from the east mirror in one of the stations back toward the base of the periscope. At the periscope, the second mirror will send the light back northward toward the west mirror in one of the stations. That mirror will send the light back toward the periscope again, where the third mirror will send it toward the FDLs. The LDL station positions are chosen so that delay can be introduced in 29 m increments by raising an east mirror in one station and a west mirror in either the same station or another station.

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Over the past two years, vacuum tanks, mirror mounts, and mirrors for the LDLs have been installed. The design was completed and parts ordered in the fall of 1999. The build-out of the piers was completed in the spring of 2002, and the vacuum system was completed at the end of that year. The system was populated with optics in the spring of 2003, and first-order alignment was done in the summer of 2003.

Currently, we are testing the mirror-positioning mechanism for drift and repeatability. We are also designing operational controls and carrying out second-order alignment. The mechanical elements (mirror mounts and slides) needed for joining the LDLs to the feed system at the base of the periscopes have been designed and ordered.

2. THE LDL "POPUP" MECHANISM

Each of the 36 LDL stations contains two ``popup" mirror positioning mechanisms holding a 6 in flat mirror mounted in a modified Klinger gimbaled mount (see Fig. 2). The tip and tilt of the mount are adjusted with 12 V DC precision positioning screws. The platform holding the mount is driven by a pivoting link apparatus that lifts the mirror into the stellar light beam. The pivoting link has three key characteristics:

- It allows the mirror to remain in the same orientation throughout its motion.
- It requires a minimum range of motor torque throughout the motion.
- Its metal lead screw and Teflon-lined lead nut provide constant friction over a wide temperature range.

To provide repeatable positioning of the platform, the platform seats against three kinematic points (cone, groove, and flat) at the upper end of its motion. A 12 V DC gear motor drives a lead screw to lift the platform. Current-limiting control electronics provide adequate torque to seat the platform against the kinematic points. The "seating current" is limited to 0.40 ± 0.02 A above the slew current at 10 V supplied to the motor. The slew current varies with ambient motor temperature, due mostly to changes in the gear head lubricant viscosity with temperature.

3. DRIFT TESTS

The objective of the drift tests is to quantify the thermal stability of the LDLs by measuring the drift rate, magnitude, and range of the mirror orientation. The drift rate must not exceed the 15 Hz update rate of the star tracker ("narrow angle tracker," or NAT), and the drift magnitude during a single observation (typically 180 s) cannot exceed the 25 arcsec maximum excursion of the NAT.

The equipment for the procedure consists of a Brunsen Model 2030 alignment telescope with a custom V block mount, a Warren-Knight CCD camera mounted on the alignment telescope, WinTV/Hauppauge video capture hardware and software, and custom centroiding software (see Fig. 3). The procedure consists of the following steps:

- Set up the alignment telescope/CCD camera combination on the V block mount. The combination is mounted on an optical table between the periscope LED target (where light from the feed system will be directed into the LDL) and the window at the beginning of the LDL vacuum tank.
- Align the V block mount to be collinear with the periscope LED target and the LED target at LDL station 6 (100 m distant). This step includes pointing the telescope first toward the periscope LED target, and then reversing the telescope to point toward the target at station 6. The adjustment is complete when both targets are centered in the CCD camera.
- Adjust the pointing of the LDL station 6 mirror. The mirror is tipped/tilted until the second periscope LED target appears centered in the CCD camera.
- Install an environmental cover over the telescope and camera. We then allow three days for the telescope and camera to thermally equilibrate. (Note that the periscope and alignment telescope are in a temperature controlled room, stable to 1/4 C.)

- Raise the LED target in station 6 and record time-lapse images to establish the stability of the telescope and mount.
- Raise the second periscope LED target and record time-lapse images to establish the drift of the LDL mirror pointing.

In the stability test for the telescope and mount, we recorded images at 4 min intervals over a 48 h period and measured the movement of the image centroid. We determined that the motion of the telescope and camera is < 1 arcsec.

The results of the stability test for the LDL mirror show that its drift is strongly correlated with the ambient temperature of the LDL station, which is outside the laboratory building (see Fig. 4). The drift is mainly vertical. During the two days of our tests, the total excursion was a maximum of 21 arcsec, but over a single night, the range was much smaller, around 10 arcsec. The drift rate and amplitude were well within the NAT's capabilities.

3. CONCLUSIONS

The thermally-induced pointing drift of the LDL mirror we sampled is within the desired range. We required that the maximum drift be < 25 arcsec during an observation (typically 180 s) and that the rate of drift be within the capabilities of the NAT. The NAT can achieve a rate of 0.11 degrees per second (400 arc-seconds per second) over its full range of motion. Our measurements showed a drift of < 1 arcsec during an observation (approximately 0.005 arc-seconds per second), < 10 arcsec during a single night, and < 25 arcsec over several days. We found that the drift is closely correlated with ambient temperature.

We have considered some possible improvements. Drift amplitudes verses ambient temperature could be accounted for or further reduced. Lookup tables of mirror tip/tilt vs. temperature could be generated to speed alignment during array reconfiguration. Internal radiation reflectors and mount modifications could reduce drift amplitude; however, they would be expensive. Finally, sun shading of the LDL stations is currently being investigated.

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REFERENCES

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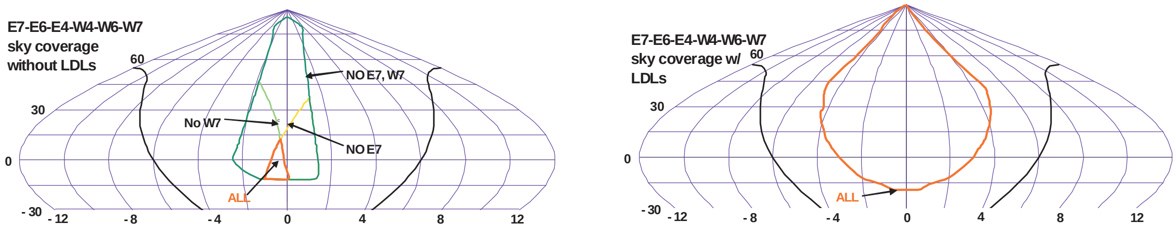

Fig. 1: NPOI sky coverage without (left) and with (right) the LDLs. The array used in this example has a maximum baseline length of 97 m.

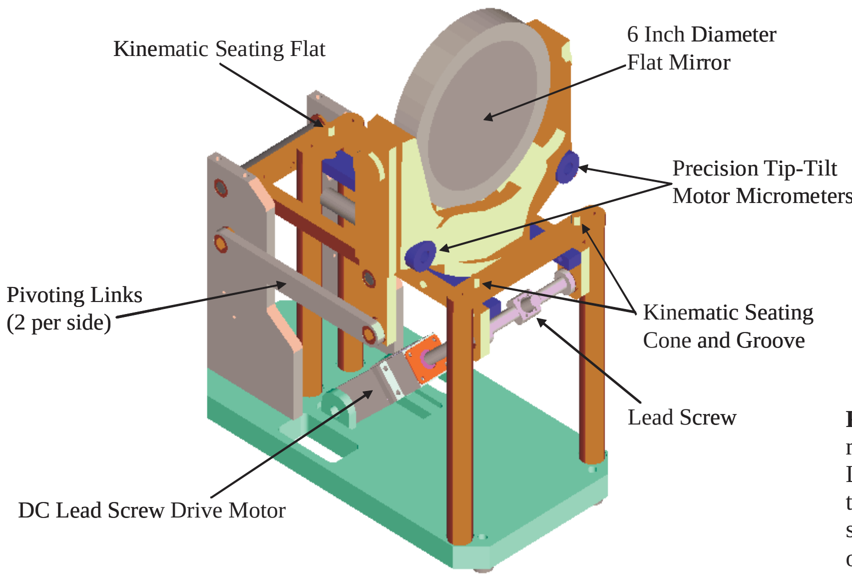

Fig. 2: The LDL popup mechanism. Each of the 36 LDL stations has two popups that can be raised into the stellar light beam or lowered out of the beam.

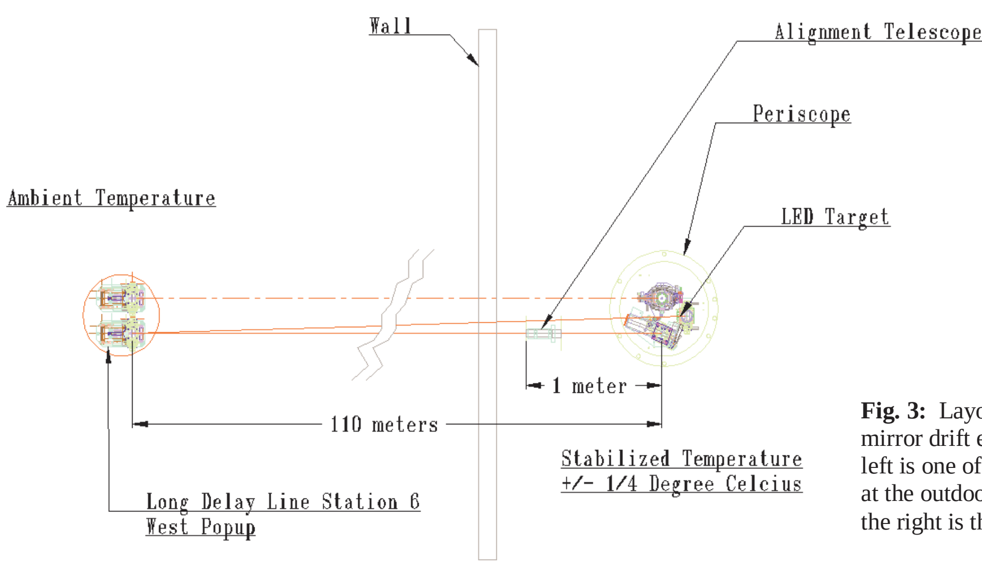

Fig. 3: Layout of the LDL mirror drift experiment. On the left is one of the LDL stations, at the outdoor temperature. On the right is the periscope

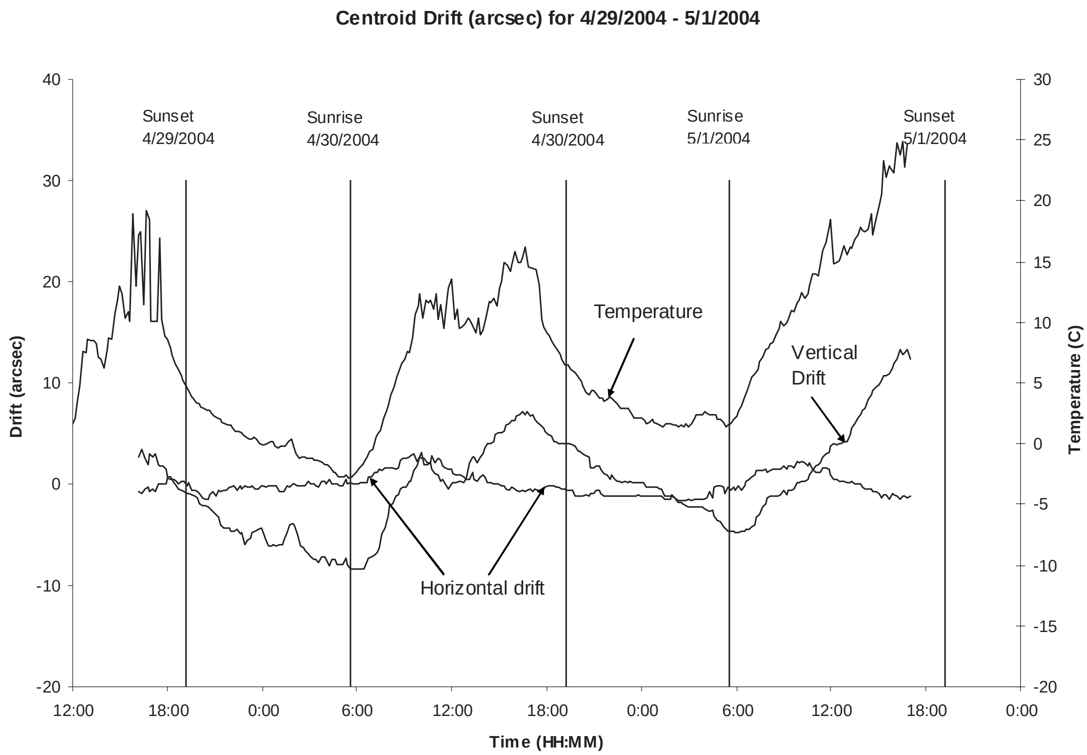

Fig. 4: Vertical and horizontal pointing drift measurements, and LDL temperature measurements, for LDL station 6 west mirror. The pointing drift was primarily vertical, and closely correlated with the temperature. The total excursion is within the pointing compensation capabilities of the NPOI tip/tilt compensation.